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II.

CONTRIBUTIONS FROM THE ZOÖLOGICAL LABORATORY OF THE MUSEUM OF COMPARATIVE ZOÖLOGY AT HARVARD COLLEGE.

No. I. — ON THE DEVELOPMENT OF THE POSTERIOR FISSURE OF THE SPINAL CORD, AND THE REDUCTION OF THE CENTRAL CANAL, IN THE PIG.*

By William Barnes.

Presented June 13, 1883, by Alexander Agassiz.

It is well known that the anterior and posterior fissures of the spinal cord are not produced in the same manner. While the formation of the anterior fissure results from a comparatively simple process of growth and enlargement in the region of the anterior horns, the production of the posterior fissure appears to be dependent on more complicated changes. More or less intimately connected with its formation is the disappearance of a portion of the original lumen of the neural tube. Whether, however, the posterior fissure is "a part of the original neural canal separated from the rest of the cavity by a median coalescence of the side walls," as claimed by Foster and Balfour; or whether the atrophy of a portion of the canal is only a necessary antecedent to the formation of the fissure; or whether, finally, its obliteration may be considered as causally connected with the appearance of the fissure, — appear still to be questions which have not received their definite answer.†

It was with a view to gaining additional information on these points that the following investigations on the pig were undertaken.

Literature.

Clarke, J. L.

'62. Researches on the Development of the Spinal Cord in Man, Mammalia, and Birds. Philos. Trans. Royal Soc. London, 1862, pp. 911–938, Pl. XLV.–XLVIII.

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* The following investigations were made in the Embryological Laboratory of the Museum, under the supervision of Dr. E. L. Mark.

† Balfour ('81, p. 344) says, "The exact mode of its formation appears to me to be still involved in some obscurity."

Balfour, F. M.

'80. A Treatise on Comparative Embryology. Vol. I. xi + 492 pp., 275 figs. London: Macmillan & Co.

'81. Same. Vol. II. xi + 655 + xxii pp., 429 figs.

Bidder, F., und Kupffer, C.

'57. Untersuchungen über die Textur des Rückenmarks und Entwickelung seiner Formelemente. viii + 121 pp., 5 Taf. Leipzig.

Foster, M., and Balfour, F. M.

'74. The Elements of Embryology. Part I. xix + 266 pp., 71 figs. London: Macmillan & Co.

Kölliker, A.

'61. Entwickelungsgeschichte des Menschen und der höheren Thiere. vi + 468 pp., 225 figs. Leipzig.

'79. Same. 2d edition. xxxiv + xvi + 1033 pp., 606 figs. Leipzig.

Loewe, L.

'80. Beiträge zur Anatomie und zur Entwickelungsgeschichte des Nervensystems der Säugethiere und des Menschen. Bd. I. Die Morphogenesis des centralen Nervensystems. xiii + 126 pp., 18 Taf. Leipzig.

Lubinoff.

'74. Embryologische und histogenetische Untersuchungen über das sympathetische und centrale cerebrospinal Nervensystem. Virchow's Archiv f. Physiol., Bd. LX. pp. 217–273, Taf. VII. and VIII.

Remak, Robert.

'55. Untersuchungen über die Entwickelung der Wirbelthiere. vi + xxxviii + 195 pp., 12 Taf. Berlin: G. Reimer. 1850, 1851, 1855.

Waldeyer, W.

'76. Ueber die Entwickelung des Centralkanals im Rückenmark. Virchow's Archiv f. Physiol., Bd. LXVIII. pp. 20–26, 6 Holzschn.

Nothing is said concerning the formation of the posterior fissure by the earlier writers on the development of the nervous system. Even Remak ('55) does not enter into this subject.

Bidder and Kupffer ('57, p. 114) say that in the chick embryo, between the eighth and ninth days of incubation, the white substance of the posterior columns has grown around the posterior segment of the cord, so that only a small gap, the posterior fissure, remains between the columns. They do not attempt to pursue further the process which gives rise to this fissure.

In the first edition of Kölliker's *Entwickelungsgeschichte des Menschen*, etc. ('61, p. 262), incidental to an account of the gradual obliteration of the dorsal part of the central canal, there is a short description of cross sections of the cord at various stages in the development of man, which affords some insight into the processes accompanying the formation of the posterior fissure. In human embryos of about six weeks the central canal is diamond-shaped on cross section; its epithelium is of nearly uniform thickness except in the dorsal part.

In the median portion of this region it is exceedingly thin, whereas on either side it presents swellings which in cross section have a knob-like appearance. In this region the epithelium is not covered by either the gray or the white substance of the cord.

In embryos of nine or ten weeks a cross section of the cord shows, according to Kölliker, the posterior columns raised into two parallel ridges. The floor of the shallow furrow embraced between them, which he says is the actual posterior fissure, is formed by the outwardly convex surface of the epithelial lining of the central canal.

Later these elevations come to lie close together, so that only a narrow slit is found between them; yet they do not coalesce. Even in the third month there is a connective-tissue partition between them. They become more and more reduced to the level of the surface of the cord, and a kind of separation takes place within, which results in splitting them off as two wedge-shaped bands, which he calls the Goll'sche Keilstränge.

No account is given of the manner in which the furrow is deepened.

Clarke ('62, p. 916) describes the formation of the posterior fissure as follows: —

"At the commencement of these changes," i. e. those which lead to the formation of the posterior fissure, "the central canal reaches the surface of the posterior gray substance. The growth of this substance is then continued, not only backward, but *outward* from the mesial line, while in the intervening angular and gradually increasing space between it and this line are developed on each side two new pyramidal columns of longitudinal fibres, which increase in depth in a corresponding proportion.

"Of these the outer one, which is much the larger, rests on the back of the cornu, over which it ultimately blends with the *outer* portion of the posterior columns previously developed.

"The inner and smaller column is in general more conspicuous and distinct in the dorsal and cervical than in the lumbar region. The opening between these additional columns constitutes the posterior median fissure, which is now occupied by blood and pia mater in connection with radiating fibres from the central epithelial layer."

Foster and Balfour ('74, p. 187) give a very different account of the formation of the fissure. In the embryo chick of seven days the central canal is divided, according to these authors, into two parallel tubes by the median coalescence of its lateral walls, thus forming a dorsal and a ventral canal. Afterwards the roof of the dorsal canal is partially absorbed, thus converting the canal into a wedge-shaped fissure, whose mouth, however, is closed by a triangular clump of elongated cells. Below this mass of cells the fissure is open. In the lumbar and sacral regions the two canals still communicate.

Thus the posterior fissure is claimed to be part of the lumen of the original neural canal.

Lubinoff ('74, Pl. VII.) figures the same elevations of the posterior columns that Kölliker has described, but does not deal with the development of the fissure.

Waldeyer ('76, p. 23) says that the canal closes dorsally by an ingrowth of cells. Afterwards the median part of the posterior columns grows towards the central canal on each side of the median plane. These always grow from the already formed parts of the posterior columns.

After reproducing the substance of his earlier account of the formation of the fissure in man, Kölliker ('79, p. 597) says that in the embryo rabbit the posterior columns, after reaching, on the seventeenth day, the posterior median line, grow inwards toward the central canal, apparently without the formation of any Keilstränge.

In the case of the sheep, Loewe ('80, p. 75) finds the first trace of the posterior fissure in embryos of 1.5 cm. The Goll'sche Keilstränge also appear at this stage. Between the pyramids there are fibres corresponding to the anterior horn fibres. They later develop into the posterior horn fibres.

In embryos of 2 cm. the Keilstränge occur as two lateral formations, rounded ventrally, and lying close to one another. They are somewhat divergent behind, thus embracing an opening, the posterior median fissure. The Keilstränge are formed very late, but develop fast in comparison with the other columns. He does not state in what manner this fissure becomes deepened.

Balfour ('81, p. 344) confesses that he has "some doubts as to the complete accuracy" of the conclusions to which Foster and he had previously arrived ('74, p. 187). He thinks it probable that the dorsal fissure is a direct result of the atrophy of the dorsal part of the central canal. Dorsally the walls of the canal coalesce, and the fusion gradually proceeds ventralwards, so as to reduce the canal to a minute tube. The epithelial wall formed by this fusion on the dorsal side of the canal is gradually absorbed.

"The epithelium of the central canal at the period when its atrophy commences is not covered dorsally either by gray or white matter, so that with the gradual reduction of the dorsal part of the canal and the absorption of the epithelial wall, formed by the fusion of its two sides, a fissure between the two halves of the spinal cord becomes formed." This is the posterior fissure. During its formation the white matter of the dorsal columns becomes prolonged so as to line its walls.

MATERIAL.

The present investigations were made exclusively on embryos of the pig.

When sufficiently small these were placed for a few hours in picro-sulphuric acid,* and then hardened in alcohol. In the latter process stronger grades were gradually substituted for the weaker, beginning with 70 per cent.

To render embryos in which ossification had begun suitable for sectioning, they were either placed *in toto* in picro-nitric acid long enough to remove the salts of lime and then hardened, as in the case of younger embryos, or the desired portions were cut from the embryos and treated in the same manner.

Most of the specimens thus prepared were stained in a neutral aqueous solution of carmine before cutting; some, however, were stained in picro-carmine; the results were less satisfactory with the latter method.

The measurements were taken from the tip of the nose to the root of the tail following the curvature of the back.†

OBSERVATIONS.

In embryos 43 mm. long cross sections through the posterior part of the lumbar enlargement show that the dorsal wall of the central canal is still composed exclusively of epithelial cells.

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* Kleinenberg's preparation, viz.: Sat. aq. sol. picric acid, 100 parts; conc. sulphuric acid, 2 parts; diluted with three times its volume of distilled water.

† The following table will enable the reader more easily to compare the stages I have employed with those used by other observers, who have usually given the length as measured from the mid-brain to the most distant point of the embryo in its normal curved position.

Measured along the curvature.	Measured in a straight line.
43 mm.	23 mm.
54 "	29 "
65 "	35 "
100 "	65 "
125 "	78 "

The cuticula interna (Pl. III. fig. 1, *i*) presents a marked thickening along the dorsal edge of the still slit-like central canal.

There is in the dorsal wall of the canal in the median plane a tract which is destitute of nuclei; it is composed of fibres differentiated from the epithelial cells the nuclei of which lie at their peripheral ends; the central ends of the fibres abut upon the cuticula interna. These nuclei are granular and oval, the longer axis having a dorso-ventral direction. It seems probable from the arrangement of the fibres and nuclei that the latter remain practically fixed, while the cells to which they belong — inasmuch as they are attached to the cuticula interna, which retreats with the restriction of the canal — are drawn out into fibres, which later are metamorphosed into the posterior horn fibres. More and more of the cells from the lateral epithelial walls of the canal are drawn in towards the median plane as the closure proceeds.

The posterior white columns (Pl. III. fig. 1, *h*) have not yet reached the dorsal median line, but as seen in cross sections appear to gradually thin out as they approach it.

In the dorsal region the nuclei are somewhat more elongated, but their extremities are still rounded. The lumen of the canal is of about the same shape as in the cervical region, but it is somewhat less restricted (Pl. I. fig. 2).

In embryos 54 mm. in length cross sections through the cervical region (Pl. III. fig. 2) show that the white columns have approached much nearer the median plane; there is, however, between their proximal edges and this plane a space which is filled with a reticulum that is directly continuous with the gray substance. In the deeper parts of this tract there are many nuclei, but as one approaches the surface of the cord they gradually disappear. The white columns have already begun to grow towards the central canal, there forming two inwardly projecting horns, afterwards known as the Burdach'sche Keilstränge. In the median plane there is a kind of partition formed of fibres which are derived from the epithelial cells of the primitive canal; it extends from the dorsal edge of the canal to the surface of the cord.

Pl. III. fig. 3, shows a section through the lumbar region of the same embryo. Here the posterior columns have not yet begun to develop towards the central canal. The restriction of the canal has not proceeded so far as in the cervical and dorsal regions. Compare Pl. I. figs. 7 and 8.

In the sacral region (Pl. I. fig. 8) the epithelium of the central canal still extends to the surface of the cord.

The degree to which the posterior columns approximate each other varies considerably both in the different regions of the same embryo and in the corresponding regions of different stages, as may be seen from the outlines (Pls. I. and II.); in some sections the space between them is so narrow as to leave room for only one or two fibres. A few nuclei are constantly found in the fibrous substance occupying this intercolumnar space while there are as yet none in the columns themselves.

Already at this stage there are indications of fibres running across the median plane, just ventral to the posterior columns, and serving to connect the posterior horns. These fibres are probably connective tissue, and not nervous elements.

In Pl. III. fig. 4, from the lumbar enlargement of the same embryo, is shown the relation the nuclei bear to the posterior horn fibres. The latter expand into a brushlike enlargement, one end of which is merged in the cuticula interna, while the corresponding nuclei are situated at a considerable distance from the cuticula.

Cross sections through the posterior lumbar region of embryos 60 mm. long (Pl. III. fig. 5) show a pair of cords (G), composed of a coarse network of fibres, occupying the space between the posterior columns. They are more firmly connected with the pia mater than is the white substance of the columns, as is proved by the fact that they maintain their connection with the pia, while the white substance is separated from it by the shrinkage due to the hardening fluids. These cords contain nuclei which have a granular appearance. I am inclined to consider this apparently granular condition the result of the nuclear metamorphosis which immediately precedes cell division, and consequently that the cells composing this tissue are still undergoing rapid proliferation. The columns diverge at their dorsal edges, embracing between them a triangular space filled with a network of more delicate fibres than those of the cords themselves. Undoubtedly these cords are merely the result of a further modification of the cells embraced between the columns in the preceding stages. The position of the nuclei indicates at least that they are genetically connected with the nervous cord rather than its pia-mater sheath.

The connection between the posterior horns is very plainly marked at this stage, the round homogeneous nuclei of the gray substance being in striking contrast to the oblong reticulated nuclei of the epithelium. In this stage nuclei are also found in the posterior columns; they make their appearance first near the deeper margin of the white substance, as may be seen in Pl. III. fig. 5.

Sections from the lateral columns (Pl. III. fig. 7) indicate clearly, I believe, that what Kölliker ('79, p. 596) has ventured to suggest as *possible* is in reality the only rational explanation of the presence and position of these nuclei. They exist, as Kölliker has said, independently of the blood-vessels. It is also quite certain, from the position they occupy when first seen, that they must have been derived from the gray matter of the cord.

The columns have by this time (Pl. III. fig. 6) become thickened along their median edges, and begun to grow ventralwards along the outer margins of the tract occupied by the horn fibres.

The posterior columns are already divided into numerous fasciculi of various shapes by connective-tissue septula, which have in general a radial direction extending from the gray substance toward the pia mater.

When embryos have reached the length of 85 mm. the Burdach'sche Keilstränge (Pl. III. fig. 11, B) extend in the cervical region about half-way from the periphery to the central canal, and have pressed together closely the distal ends of the above-described cords, which now may properly be called the Goll'sche Keilstränge. The latter are separated from each other only by the partition of horn fibres before mentioned.

At their distal edges Goll's Keilstränge are distinct from Burdach's, being separated from them by processes of connective tissue which are continuous with the pia mater; at their proximal margins, however, they can only be distinguished from them by the different directions which the fasciculi take in the two cases; in the former, their ventral edges trend towards the median plane, whereas the corresponding edges of the latter have a direction away from this plane. They cannot be distinguished by their histological structure; neither by the size of the nerve fibres nor by the size and arrangement of the fasciculi. Both are composed of fine longitudinal fibres arranged in fasciculi which are separated from each other by connective tissue.

The nuclei have nearly all disappeared from the Goll'sche Keilstränge, the few that remain presenting a more ragged appearance than in the previous stages.

The further development of this region may be summarized in a few words. It results from the apparent infolding of the posterior columns that the white substance approaches nearer and nearer to the canal, pushing before it the transverse connective-tissue fibres, which thus come to make a broad ventrally convex curve, the ends of which (Pl. III. fig. 11) sweep up along the lateral margins of Burdach's Keilstränge.

The growth of the Burdach'sche Keilstränge towards the central canal does not take place with uniform rapidity in all parts of the cord, neither is there an uninterrupted gradation in the advancement of this process from one end of the cord to the other; they grow much more rapidly in the cervical and lumbar enlargements than elsewhere.

There seems to be no causal connection between the closure of the canal and the development of the posterior fissure, since the dorso-ventral diameter of the canal is very frequently reduced to nearly its minimum length before the white substance of the posterior columns, on the morphological condition of which the presence or absence of the fissure depends, begins to grow ventralwards.

In embryos measuring 125 mm. and upwards the canal is so reduced as to appear in cross sections like a round or slightly oval opening, but in the dorsal and sacral regions of many of these embryos there is scarcely a trace of an ingrowth on the part of the posterior columns. (Compare Pl. II. figs. 30, 32.) Later stages in the development are shown in Pl. II. figs. 33-36.

Until the embryos have grown to the length of 186 mm., the latest stage I have sectioned, the posterior fissure remains closed, i. e. the walls of the Goll'sche Keilstränge remain close together, being only separated by the horn fibres which completely fill the space between them. In the dorsal and sacral regions, even at this advanced age, the Keilstränge have made very little progress towards the canal.

In no stage is there any evidence of a direct median coalescence of the facing walls of the canal. If such fusion actually occurred, one should find, in some sections at least, a keel-like blade of cuticula projecting dorsally from the cuticula interna which lines the roof of the canal at all stages; or, in the event that the fusion were to occur more promptly near the centre of the canal than along its dorsal edge, there might even be a vertical blade of the cuticular substance entirely separated from the cuticula lining the roof of the persistent portion of the canal. But such structures are never to be observed, the cuticular lining of the roof of the canal always presenting an even curved outline, not only for the face which looks inward toward the lumen of the canal, but also for that which is directed away from it.

It is therefore evident that the lumen of the canal is restricted from the dorsal towards the ventral side by a gradual and continuous process, which causes a shifting of the epithelial cells and makes their long axes pass from a direction perpendicular to the median plane into one more nearly parallel with it, as the cells are successively brought into the region of coalescence.

The posterior fissure, so called, is carried ventrally with the Burdach'sche Keilstränge, either contemporaneously with this restriction of the canal, though more slowly, or else not until after the restriction is far advanced.

REDUCTION OF THE CENTRAL CANAL.

LITERATURE.

According to most authors the central canal of the spinal cord in the adult is formed from the ventral portion of the primitive canal. Thus Kölliker ('61, p. 261) says that the primitive canal undergoes a gradual atrophy from the dorsal edge ventralwards, and that its obliteration is due to the increase in size of the posterior columns.

Balfour and Foster ('74, p. 186) claim that in the chick the canal is divided into two portions, a dorsal and a ventral, by the median coalescence of its walls, and that the ventral becomes the permanent canal.

Waldeyer ('76, p. 23) takes the same view as Kölliker.

The latter still ('79, p. 590) maintains the same opinion as in his previous writings on this topic.

According to Loewe ('80, p. 119), however, the primitive canal suffers a reduction of its caliber both dorsally and ventrally. He bases his conclusion on the fact that the epithelial cells at the anterior (ventral) edge of the canal have an arrangement of nuclei and fibres similar to that of the cells at the posterior edge; i. e. the nuclei are situated at the peripheral ends of the cells, while the central ends have a clear fibrous appearance. He says that the fibrous ends of these epithelial cells coalesce just as they do on the dorsal side, and that they are in a similar way transformed into horn fibres.

Balfour ('81, p. 345) says that the walls of the canal coalesce dorsally, and that the coalescence then proceeds ventralwards, so that finally it reduces the canal to a minute tube formed of the ventral part of the original canal.

OBSERVATIONS.

It can be shown from a series of measurements of the absolute length of the epithelium forming the floor of the canal, together with measurements of the distance from the lumen of the canal to the bottom of the anterior fissure, that there is neither a gradual change in the former nor a corresponding increase of the latter, as would naturally be expected if the canal closes along the ventral as well as the dorsal side. There is, it is true, a variation in the thickness of the epithelium and in the other measurements, but it shows no gradation correlated to the gradual increase in the size of the cord. (Compare table, p. 108.)

Moreover, the epithelium in this region shows no marked histological change accompanying the growth of the cord. None of the changes which accompany the atrophy of the canal in its dorsal portion are visible here. There is neither a thickening of the cuticula interna on the ventral side of the canal corresponding to that which is constant along the apex of the dorsal side, nor is there a partition of horn fibres marking the line of fusion of the side walls of the canal, such as exists on the dorsal side of the canal.

In general, the canal has a broadly rounded floor, which contrasts strongly with the often fissure-like condition of the roof. This we should not expect to find if the canal closed from its ventral as well as from its dorsal side.

RÉSUMÉ.

The posterior columns after covering the posterior segment of the cord develop inwards towards the central canal as two horns known as Burdach's Keilstränge. They do not abut upon one another at first, but embrace between their approximated edges two masses of cells, one on either side of the median plane, which later become metamorphosed into Goll's Keilstränge. The latter are therefore developed independently of the posterior columns, and are not split off from them as Kölliker ('61, p. 262) has maintained. As the posterior horns develop towards the central canal, they carry between them the posterior fissure, which is filled with the horn fibres derived from the epithelial cells of the central canal.

There is neither a median coalescence of the side walls of the canal, as Balfour and Foster ('74, p. 186) describe in the chick, nor is the reduction of the canal brought about by the growth of the posterior columns, as Kolliker states ('61, p. 261); but the diminution in the caliber of the canal and the development of Burdach's Keilstränge — the latter process being accompanied by the development of the posterior fissure — are entirely independent phenomena.

The nuclei of the white substance originate independently of the blood-vessels. They appear first in those portions of the white substance lying nearest the gray matter, and are undoubtedly derived from the latter.

There is no atrophy of the ventral part of the primitive canal, as Loewe ('80, p. 119) has maintained, but the central canal of the adult represents the ventral portion of the primitive canal.

TABLE OF MEASUREMENTS.

L.	Cervical.			Dorsal.			Lumbar.			Sacral.		
	A.	B.	C.	A.	B.	C.	A.	B.	C.	A.	B.	C.
38	.222	.083	.384	.180	....	....	.194	.069	.360	.152	,055	.361
43	*.236	.111	.470	.111	.041	.369	.125	.055	.462	.125	.055	.462
47	.166	.069	.415	.125	.055	.462	.125	.069	.552	.139	.055	.396
51	*.222	.097	.437	.180	.069	.308	†.139	.055	.396	.180	.069	.308
54	*.166	.069	.415	.166	.069	.415	.111	.069	.621	.166	.069	.415
60	.139	.055	.410	.166	.069	.415	.180	.083	.406	.180	.069	.308
65	*.208	.097	.467	.236	.097	.411	.208	.083	.399	.222	.083	.384
72	.208	.097	.467	.222	.083	.384	.194	.069	.360	.264	.111	.420
80	*....	.111	....	.222	.097	.437	.222	.083	.384	.194	.069	.360
85	*.180	.083	.406	.166	.069	.415	.166	.083	.500	.152	.069	.454
93	.180	.083	.406	.166	.083	.500	†.139	.055	.396	.097	.041	.423
97	*.208	.097	.467	.166	.069	.415	†.166	.083	.500	.139	.055	.396
100	*.166	.069	.415	.166	.083	.500	.166	.083	.500	.152	.069	.454
110	*.180	.097	.524	.180	.083	.406	.166	.069	.415	.125	.055	.462
115	*.166	.083	.500	.152	.069	.454	.166	.069	.415	.111	.041	.369
125	*.150	.083	.505	.152	.069	.454	.166	.069	.415	†.166	.069	.415
135	....	....	....	.180	.083	.406	.180	.069	.308	.152	.055	.361
145	*.208	.097	.466	.180	.083	.406	†.194	.069	.360	.139	.069	.496
155	....	....	....	.180	.069	.308	.166	.069	.415	†.166	.069	.415
165	*.166	.083	.500	.139	.083	.596	.152	.069	.454	.139	.083	.596
175	.180	.083	.406	.166	.083	.500	.152	.069	.454	.111	.048	.432
185	....	....	....	.152	.069	.454	†.166	.069	.415	.166	.055	.331

EXPLANATION OF TABLE.

The foregoing summary presents in a tabulated form the results of a series of measurements of, first (column A), the distance from the anterior (ventral) edge of the lumen of the central canal to the bottom of the anterior fissure (Pl. I. fig. 1, α to γ), and, secondly (column B), the length of the epithelial cells at the anterior edge of the canal (Pl. I. fig. 1, α to β), in the cervical, dorsal, lumbar, and sacral regions of embryos from 38 to 185 mm. in length.

In the column marked L is given the length of the embryo in millimeters,* and in C, the computed ratio of measurements in column B to those in column A.

Those measurements which are marked with a star are from the cervical enlargement, and those marked with a dagger are from the lumbar enlargement.

EXPLANATION OF PLATES.

The following letters have the same signification wherever used: —

a.	Anterior white columns.
B.	Burdach'sche Keilstränge.
b.	Region of modified epithelium nearly free from nuclei.
c.	Central canal.
d.	Anterior commissure.
e.	Epithelium of the central canal.
f.	Posterior horn fibres.
G.	Goll'sche Keilstränge.
g.	Internuclear connective tissue.
h.	Posterior horns.
i.	Thickening of cuticula interna.
l.	Lateral columns.
n.	Nuclei in the white substance.
r.	Reticulum between the dorsal edges of Goll's Keilstränge.
x.	Transverse fibres connecting the posterior horns.

Plates I. and II.

[Reproduced from ink drawings by Heliotype process.]

Outlines of a series of cross sections through the cervical, dorsal, lumbar, and sacral regions of embryos from 43 to 165 mm. in length; magnified 33 diameters. All the sections in the upper row are from the cervical region; those of the second row are from the dorsal; the third, from the lumbar; and the fourth, or bottom row, from the sacral region. The corresponding sections from successive stages are not from exactly corresponding regions, which will explain the difference in size and proportions.

Figs.	1–4	from an embryo	43	mm.	in length.
“	5–8	“ “	54	“	“
“	9–12	“ “	65	“	“
“	13–16	“ “	85	“	“
“	17–20	“ “	97	“	“
“	21–24	“ “	100	“	“
“	25–28	“ “	125	“	“
“	29–32	“ “	145	“	“
“	33–36	“ “	165	“	“

Plate III.

[Reproduced by the Albertype process from pencil drawings.]

Fig. 1. A transverse section through the posterior part of the lumbar enlargement of an embryo 43 mm. in length, magnified 410 diameters. *e'*, cells formerly a part of the epithelium of the central canal.

Fig. 2. A transverse section through the cervical region of an embryo 54 mm.

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* Compare page 101.

in length, magnified 145 diameters. G′, intercolumnar mass of gray substance, the beginning of Goll's Keilstränge. B′, thickening of the posterior columns, the beginning of Burdach's Keilstränge.

Fig. 3. A cross section through the lumbar region of the same embryo, magnified 410 diameters.

Fig. 4. A cross section through the lumbar enlargement of the same embryo, magnified 410 diameters.

Fig. 5. A cross section through the lumbar enlargement of an embryo 60 mm. in length, magnified 410 diameters.

Fig. 6. A cross section through the lumbar enlargement of an embryo 100 mm. in length, magnified 145 diameters.

Fig. 7. A cross section through the lateral column and adjacent gray substance of an embryo 60 mm. in length, magnified 410 diameters.

Fig. 8. A cross section through the lumbar region of an embryo 97 mm. in length, magnified 145 diameters.

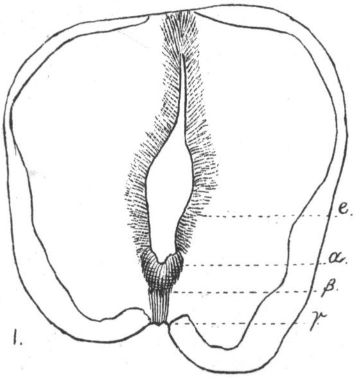
Fig. 9. A cross section through the cervical region of an embryo 145 mm. in length, magnified 145 diameters.

Fig. 10. A cross section from the lumbar region of an embryo 75 mm. in length, showing the elongation of the epithelial cells in the dorsal wall of the canal into fibres, magnified 470 diameters.

Fig. 11. A cross section through the cervical region of an embryo 85 mm. in length, magnified 410 diameters.

Fig. 12. A cross section through the dorsal region of an embryo 47 mm. in length, magnified 410 diameters, showing the disposition of the fibres and nuclei at the *anterior* wall of the central canal.

CAMBRIDGE, June, 1883.



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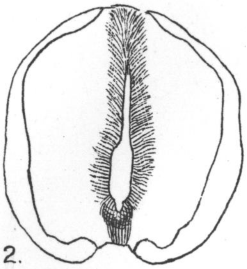

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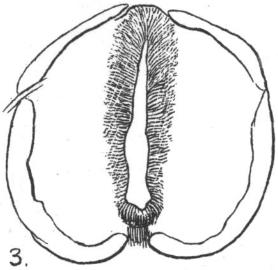

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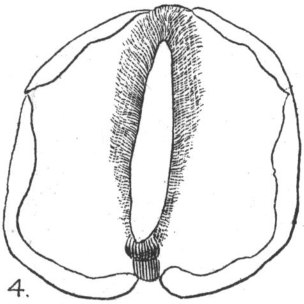

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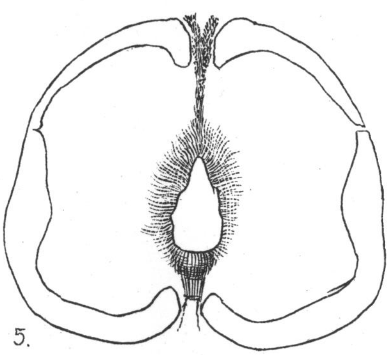

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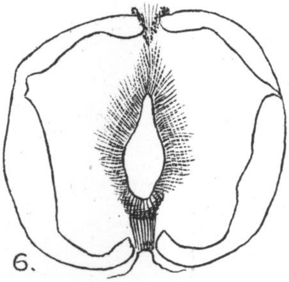

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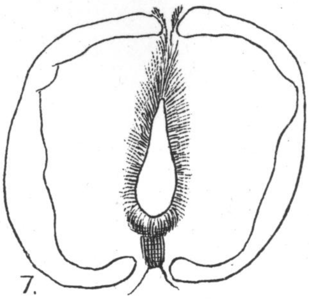

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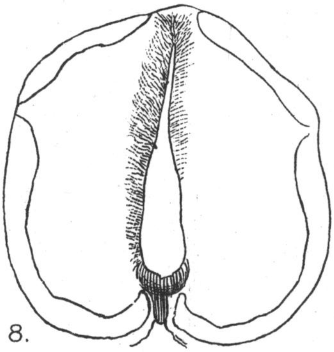

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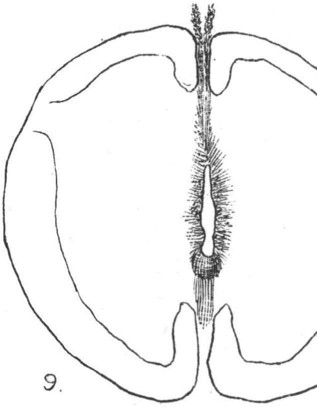

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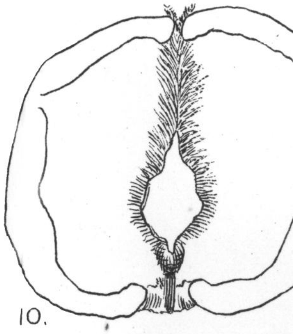

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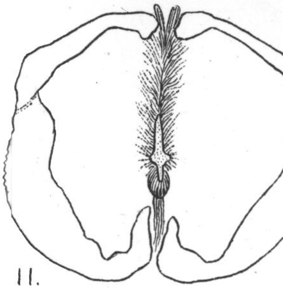

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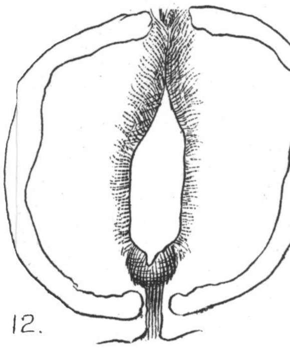

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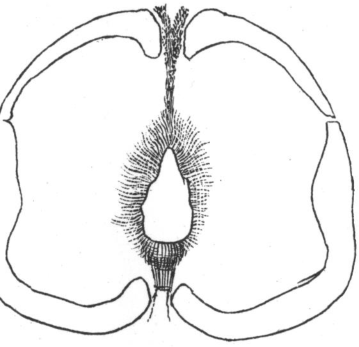
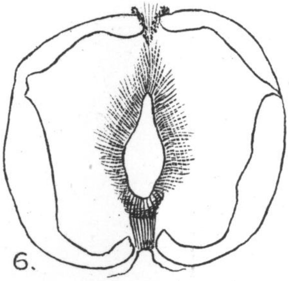
BARNES, *Posterior Fissure.* *Pl. I.*

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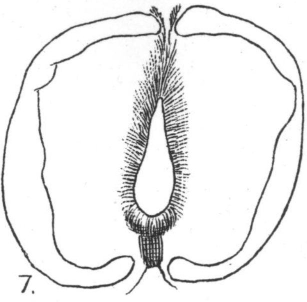
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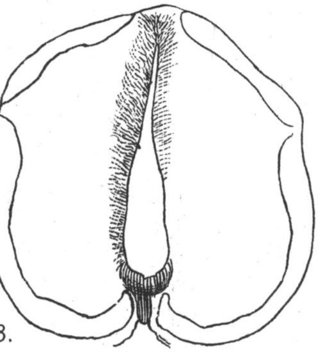
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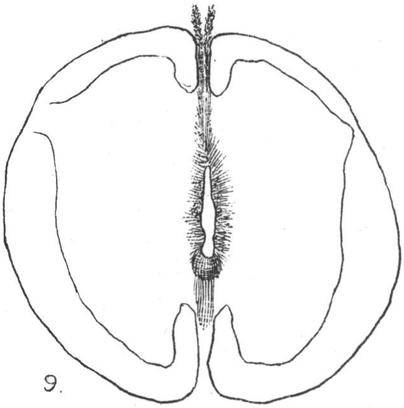
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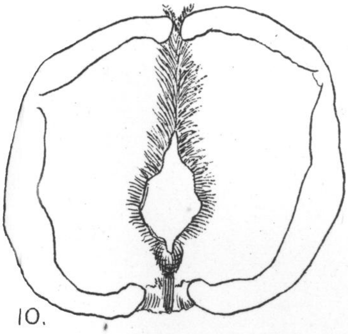
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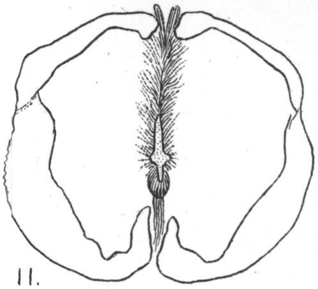
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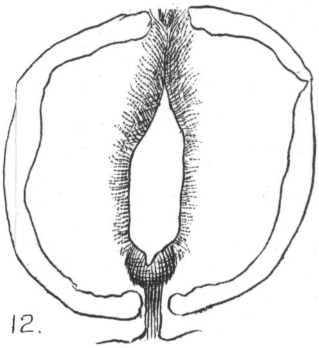
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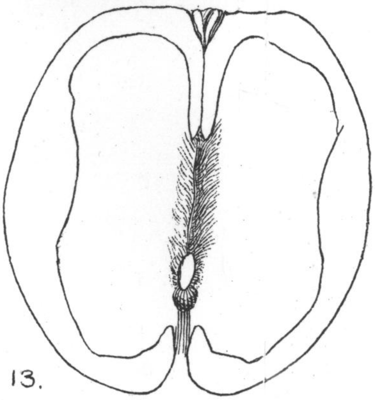
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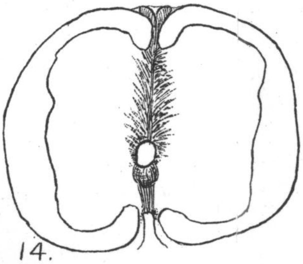
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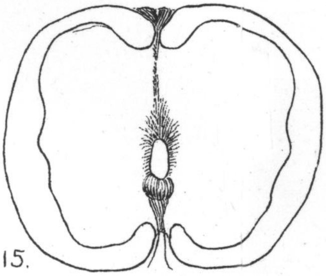
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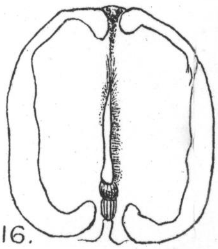
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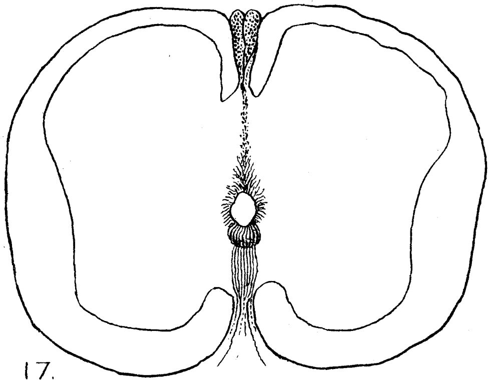

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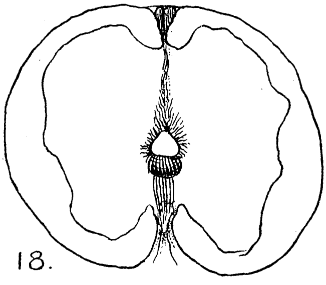

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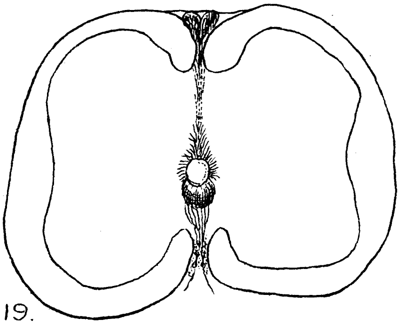

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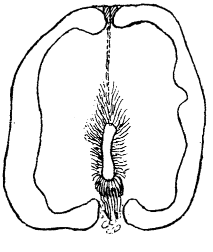

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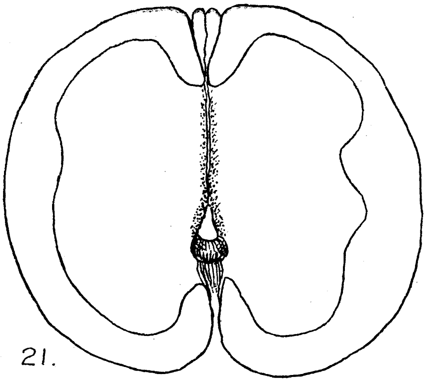

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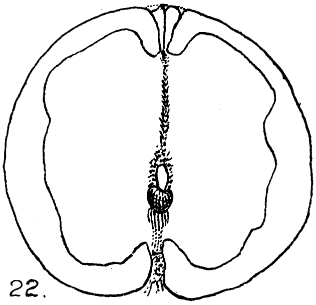

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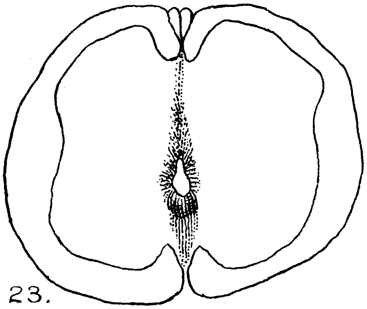

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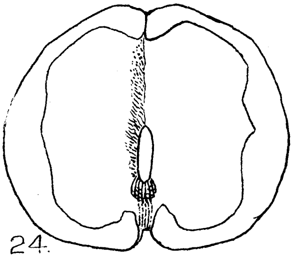

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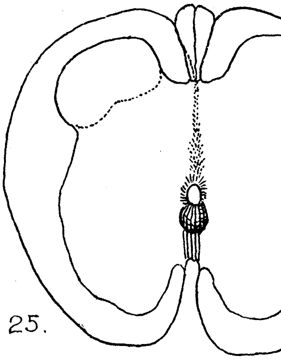

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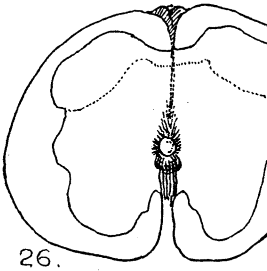

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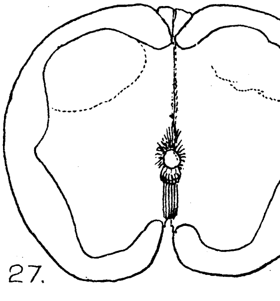

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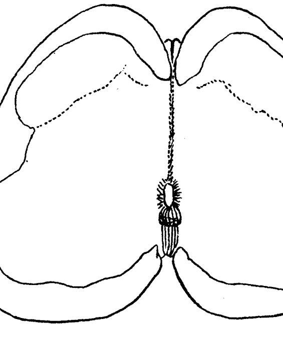

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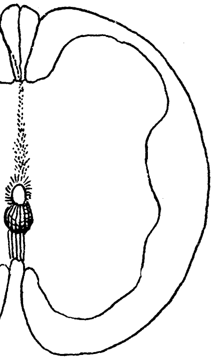

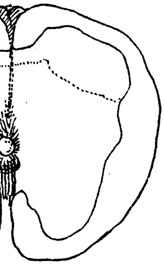

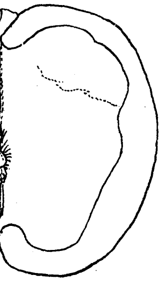

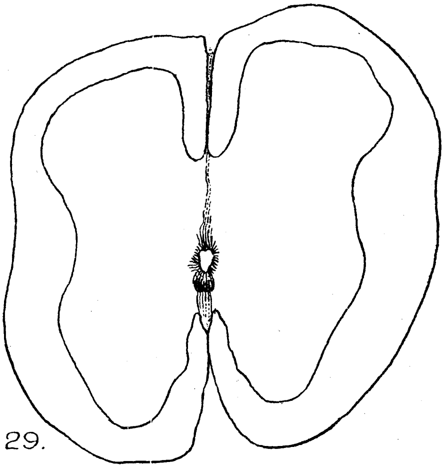

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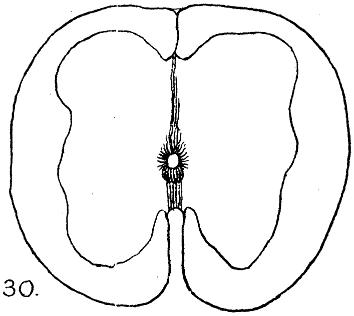

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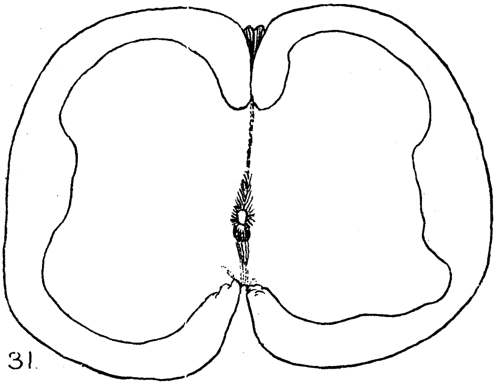

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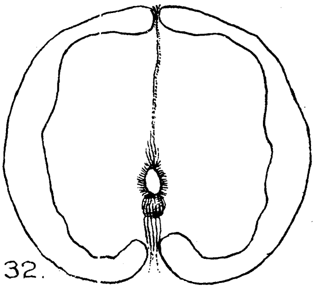

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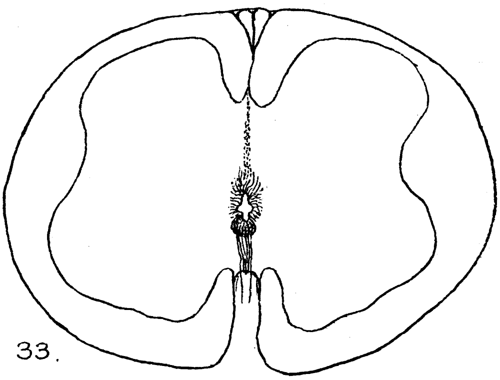

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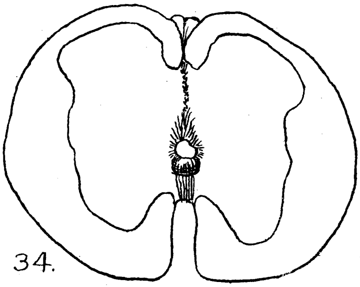

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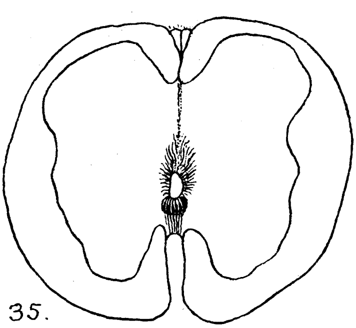

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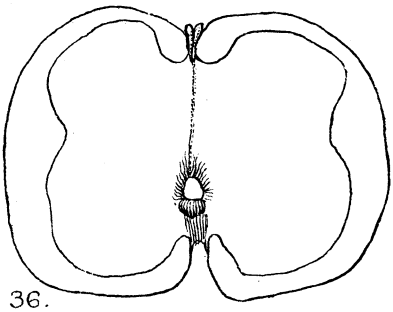

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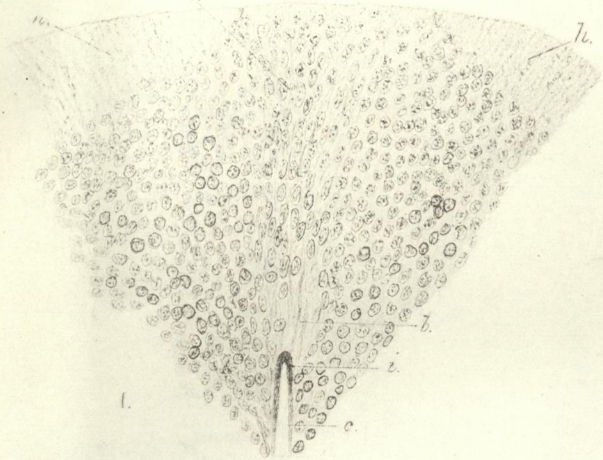

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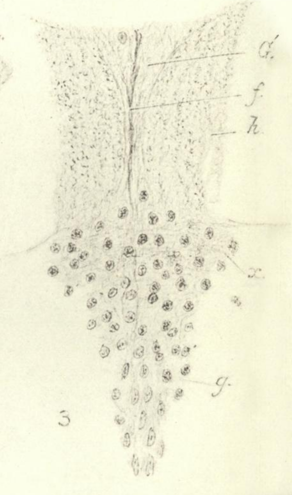

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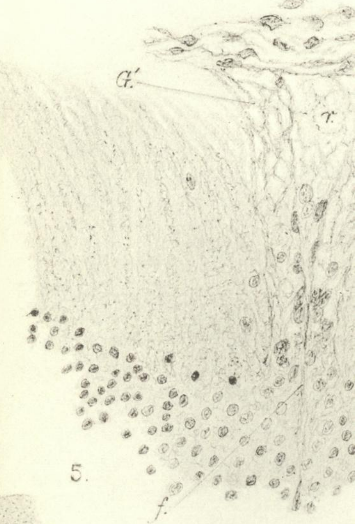

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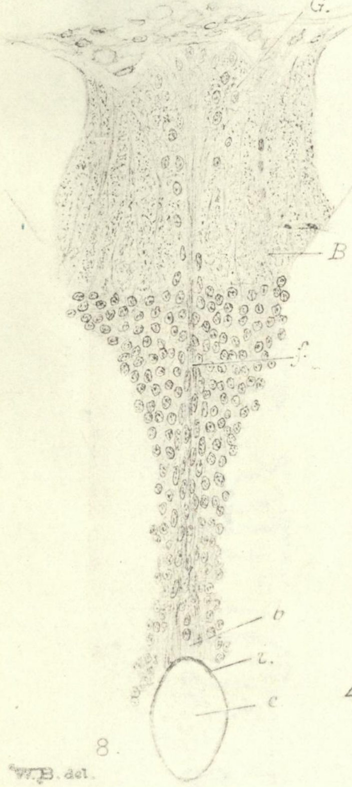

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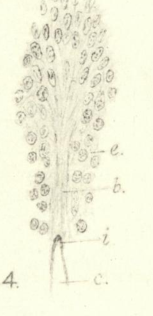

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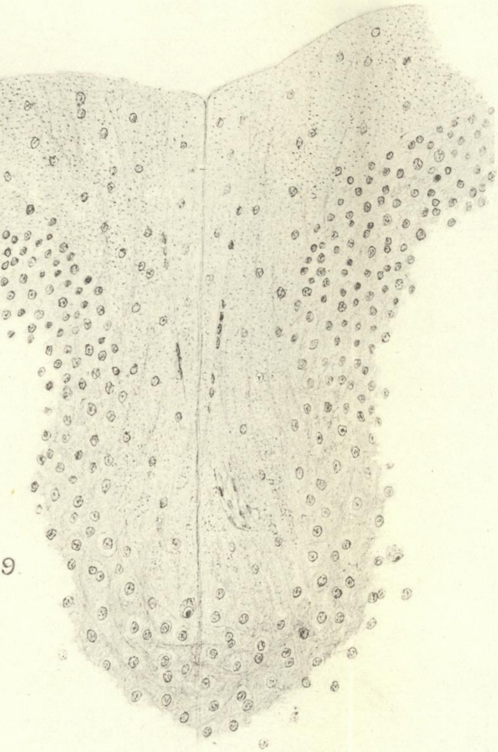

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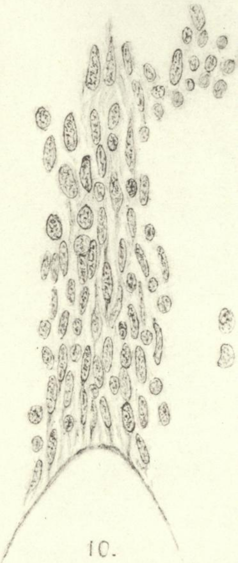

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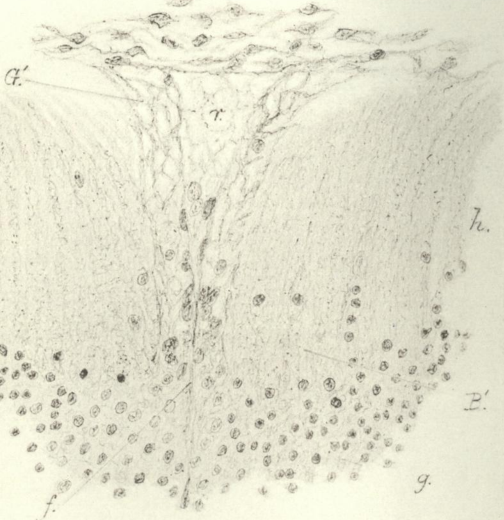

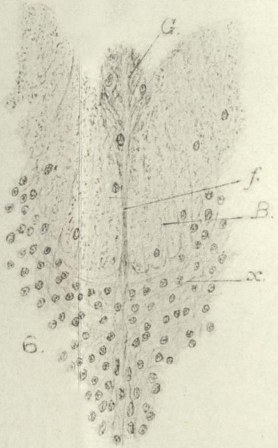

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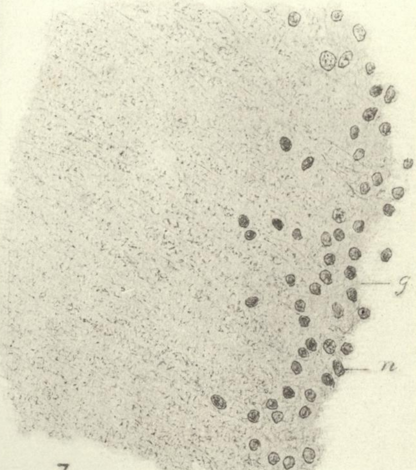

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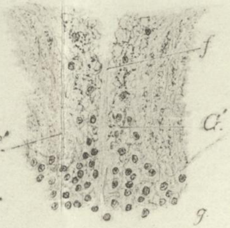

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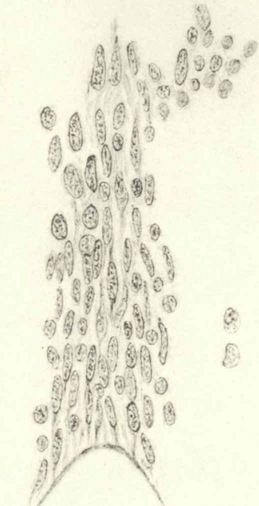

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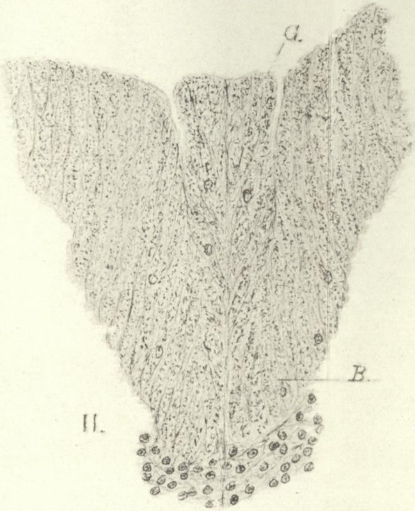

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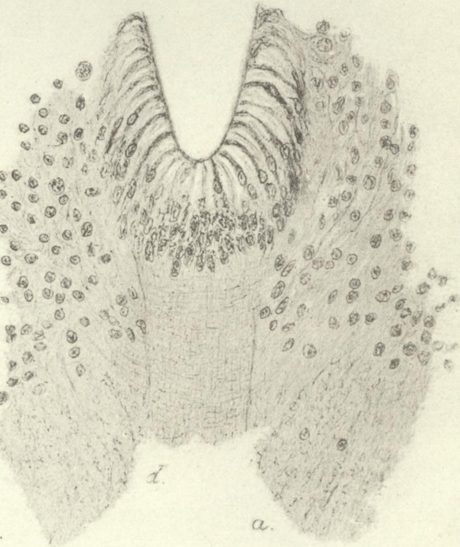

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